# Phase 2 Project Summary

**Firm: Physical Sciences Inc.**
**Contract Number: NNX12CA24C**
**Project Title: Green Liquid Monopropellant Thruster for In-Space Propulsion**

**Identification and Significance of Innovation:** Physical Sciences Inc. (PSI) investigated a unique in-space propulsion system that employs a high density, reduced toxicity ionic liquid monopropellant that is readily storable due to its low vapor pressure. The key aspect of this system is hypergolic ignition of the monopropellant, which offers superior propulsive performance compared to hydrazine. It has a low freezing point and wide liquidus range. Its low vapor pressure makes, however, a monopropellant difficult to ignite. The current state of development for ionic propellants is to employ a catalyst (e.g., 405) that must be preheated to a high temperature (~ > 400 C) for decomposition of the monopropellant. In our approach the hypergol reacts spontaneously in the liquid phase upon mixing with the liquid monopropellant and ignition occurs without the need of a catalyst. The heat released in this reaction preheats the catalyst, promoting further exothermic thermal decomposition of the monopropellant. The hypergol-initiated propulsion system is compact, requires very low to no electrical power, and offers long operational lifetime and high reliability for NASA's long-duration planetary missions.

**Technical Objectives and Work Plan:** The overall goal of Phase II was to investigate and develop a catalyst-free liquid thruster incorporating hypergolic ignition of the propellant. The specific Phase II objectives were: (1) Develop injection/ignition system designs incorporating hypergolic ignition and no catalyst, (2) Design and fabricate a 5 N scale, modular, catalyst-free, monopropellant thruster incorporating hypergolic ignition system, (3) Test the integrated injector-ignition-combustor system, (4) Evaluate the application of the hypergolic ignition method to the catalytic combustor employed in the thruster being developed for the NASA Green Propellant Insertion Mission (GPIM) program, (5) Identify propulsion system designs incorporating an ionic liquid thruster for a representative NASA mission, and (6) Conduct material compatibility evaluation for storage of the hypergol solution. The Phase II Work Plan comprised 6 technical tasks corresponding to the above six objectives: (1) Development of injection/ignition system, (2) Design and fabrication of a 5 N scale thruster, (3) Injector-Igniter-Combustor testing, (4) Evaluation of hypergolic ignition method for GPIM Thruster Catalytic Combustor being developed by Aerojet, (5) Monopropellant Thruster Design for a Cubesat, and (6) Material Compatibility Study.

**Technical Accomplishments:** The overall objective of the Phase II program, to show feasibility of a catalyst-free, hypergol assisted ionic liquid monopropellant thruster concept, was achieved during this Phase II program. Development of an integrated fuel injector-hypergolic igniter-flame holder/combustor element was conducted, and the basic feasibility of this approach was shown. The scope of this SBIR program was modified to take advantage of the opportunity with NASA's GPIM (Green Propellant Insertion Mission) by redirecting work to a catalytic thruster being developed by Aerojet Rocketdyne. In this case, hypergolic ignition was applied in the presence of a catalyst, in order to preheat the catalyst for subsequent thermal decomposition of the monopropellant, thus saving electrical power needed for catalyst preheating. The proof-of-feasibility of the novel integrated fuel injector-hypergolic igniter-flame holder/combustor element was demonstrated for both non-catalytic and catalytic applications. The optimization of element designs remains to be done, which would be best accomplished in context of specific applications under future programs. In a 2-year long material compatibility evaluation PSI has identified the following metallic and seal materials for storage/flow control components for the liquid hypergol.

**NASA Application(s):** NASA's future science missions need propulsion systems with demanding performance in challenging environmental conditions, with long operational life, and with high duty cycles. Examples of missions enabled by the propulsion technology include sampling atmospheres of planets, their moons, and other small bodies, descent and landing on their surfaces, returning soil samples from their surfaces in ascent modules, and rendezvous and docking with orbiting mother ships. Missions to the earth's moon, Venus, Mars and its moons, moons of Jupiter, and asteroids are envisioned for applications of our propulsion technology.

**Non-NASA Commercial Application(s):** Applications of the technology to non-NASA agencies include the Air Force, National Reconnaissance Organization (NRO), and the Army. Specifically, the Air Force is interested in liquid thrusters for in-space propulsion, the NRO is interested in fast response, long-life, maneuvering propulsion systems and the Army is interested in the development of green monopropellant based high pressure gas generators for pressurizing gelled propellants. Other potential DoD applications include liquid engines for propelling highly maneuverable, throttlable tactical missiles.

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